The evolution of the CEREC system

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ABSTRACT

ARTICLE 1

Background and Overview. Early in 1980, the author anticipated the attraction of restoring posterior teeth with tooth-colored material. He conducted studies and developed the clinical concept of bonded ceramic inlays, at the same time raising the issue of the fast fabrication of the ceramic restorations. The author developed plans for in-office computer-aided design/computer-aided manufacturing (CAD/CAM) fabrication of ceramic restorations specifically to enable the dentist to complete one or multiple ceramic restorations chairside, in a single appointment. The initial concept comprised a small mobile CAD/CAM unit integrating a computer, keyboard, trackball, foot pedal and optoelectronic mouth camera as input devices, a monitor and a machining compartment. CEREC 3 (Sirona Dental Systems GmbH, Bensheim, Germany) divided the system into an acquisition/design unit and a separate machining unit. Three-dimensional software makes the handling illustrative and easy both in the office and in the laboratory.

Conclusions. It appears that the CEREC CAD/CAM concept is becoming a significant part of dentistry.

Clinical implications. Sound knowledge of adhesive bonding and diligent planning are essential for the successful integration of CAD/CAM into clinical dental offices.

Key Words. CEREC; ceramic restorations; chairside computer-aided design/computer-aided manufacturing; in-office computer-aided design/computer-aided manufacturing; block ceramic; bonded restoration.
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I had been teaching operative dentistry with amalgam and gold restorations at the Dental School of the University of Zurich for 10 years when, early in 1980, I anticipated the attraction of restoring posterior teeth with tooth-colored materials. At that time, we could not use direct composite fillings because of polymerization shrinkage, the resulting formation of a marginal gap, and lack of abrasion resistance. Nevertheless, I found it imperative that posterior teeth be restored durably in their natural color in the future.

On the basis of my own in vitro and in vivo studies with pressed and hot polymerized composite inlays, I developed the hypothesis that inlays made of tooth-colored material, inserted adhesively with resin-based composite as a luting agent, could solve the problem.[1] The

DISCLOSURE: Dr. Mörmann is co-developer of the CEREC 1 system (Sirona Dental Systems GmbH, Bensheim, Germany) and president of the Foundation for the Advancement of Computerized Dentistry, and he has been awarded research grant donations by Vita Zahnfabrik (Bad Säckingen, Germany) and Ivoclar Vivadent (Scaan, Liechtenstein).

tight adhesive seal was a discovery that was confirmed later by in vitro[2] and in vivo[3-5] studies.

START OF THE CEREC EVOLUTION

If inlays solve the problem, how can the dentist produce inlays quickly at the dental chair while the patient waits? This was the question. Using conventional techniques, I had not found any convincing way to solve the problem.[1] New technology had to help. Numerically controlled machining for serial products was known in industry. Could the dentist scan individual cavities directly in the mouth of the patient quickly and use the data via computer for controlling a fast form-grinding machine?

My friend, electrical engineer Dr. sc. techn. ETHZ Marco Brandestini, was working on bloodflow ultrasound scanners at Advanced Technology Laboratories in Bothell, Wash. I visited Dr. Brandestini and casually raised my question: could cavities be scanned by ultrasound? He was skeptical at first, but when he started thinking about it, he said suddenly, "It doesn't work with ultrasound; the wavelength is too large. It must be done optically." With this realization, Dr. Brandestini's interest was awakened, and we decided to tackle the project together.

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The task of designing a technical process, from data acquisition to the finished restoration in a dental application fascinated us. We saw a new restorative world develop in front of our mental eyes. (Later we described the technical and clinical method in detail.[6]) Before Dr. Brandestini finally took the risk, he posed the $64,000 question: "How accurately do these inlays actually have to fit?" My investigations had shown that composite luting joints up to 500 micrometers wide were resistant to penetration.[4,5] This simplified the problem. Dr. Brandestini decided to return to Switzerland, where he had been educated, to tackle the subject of the optoelectronic scanning of cavities. Theoretically, 50- to 100-µm fitting accuracy in vitro appeared to be achievable, something that was confirmed in a later study.[7]

Form-grinding dental ceramics. Dental ceramic appeared esthetically more pleasing and more durable than resin-based composite. The first grinding trials with a simple device on bodies made of feldspathic ceramic (Vita Zahnfabrik, Bad Säckingen, Germany) showed that this material could be removed with a grinding wheel in a few minutes without damaging the rest of the bulk (Figure 1A). Proceeding from my grinding tests, the concept of grinding inlay bodies externally with a grinding wheel along the mesiodistal axis suggested itself (Figures 1B and 1C). In this arrangement, we could turn the ceramic block on the block carrier with a spindle and feed it against the grinding wheel, which ground from the full ceramic a new contour with a different distance from the inlay axis at each feed step. This solution proved itself in a prototype arrangement in 1983, and we implemented it in the same year in the CEREC 1 unit (Sirona Dental Systems GmbH, Bensheim, Germany) (Figures 1B, 1C and 1D). A CEREC team at Seimens (Munich, Germany), equipped the CEREC 2 with an additional cylinder diamond enabling the form-grinding of partial and full crowns (Figure 1E). CEREC 3 skipped the wheel and introduced the two-bur-system (Figure 1F). The "step bur," which was introduced in 2006, reduced the diameter of the top one-third of the cylindrical bur to a small-diameter tip enabling high precision form-grinding with reasonable bur life (Figure 1G). A good compromise between grinding efficiency, instrument life and surface roughness of the ceramic had to be chosen, and this topic was time and again the object of investigations.[1,7]

Instantaneous three-dimensional measurement of tooth preparations with an oral camera. To make sure that fast three-dimensional scanning and data acquisition of a dental preparation would be possible, we had to test the optical three-dimensional scanning technique considered by Dr. Brandestini. The idea was to project a grid of parallel stripes under a parallax angle onto the preparation according to the known principle of triangulation and to acquire the depth-dependent shift of the lines with an area sensor (that is, a charge-coupled device [CCD] video chip). Today, video chips are mass-produced, but at that time, only Fairchild Semiconductor in Palo Alto, Calif. (in the famed Silicon Valley), made them. High-tech parts such

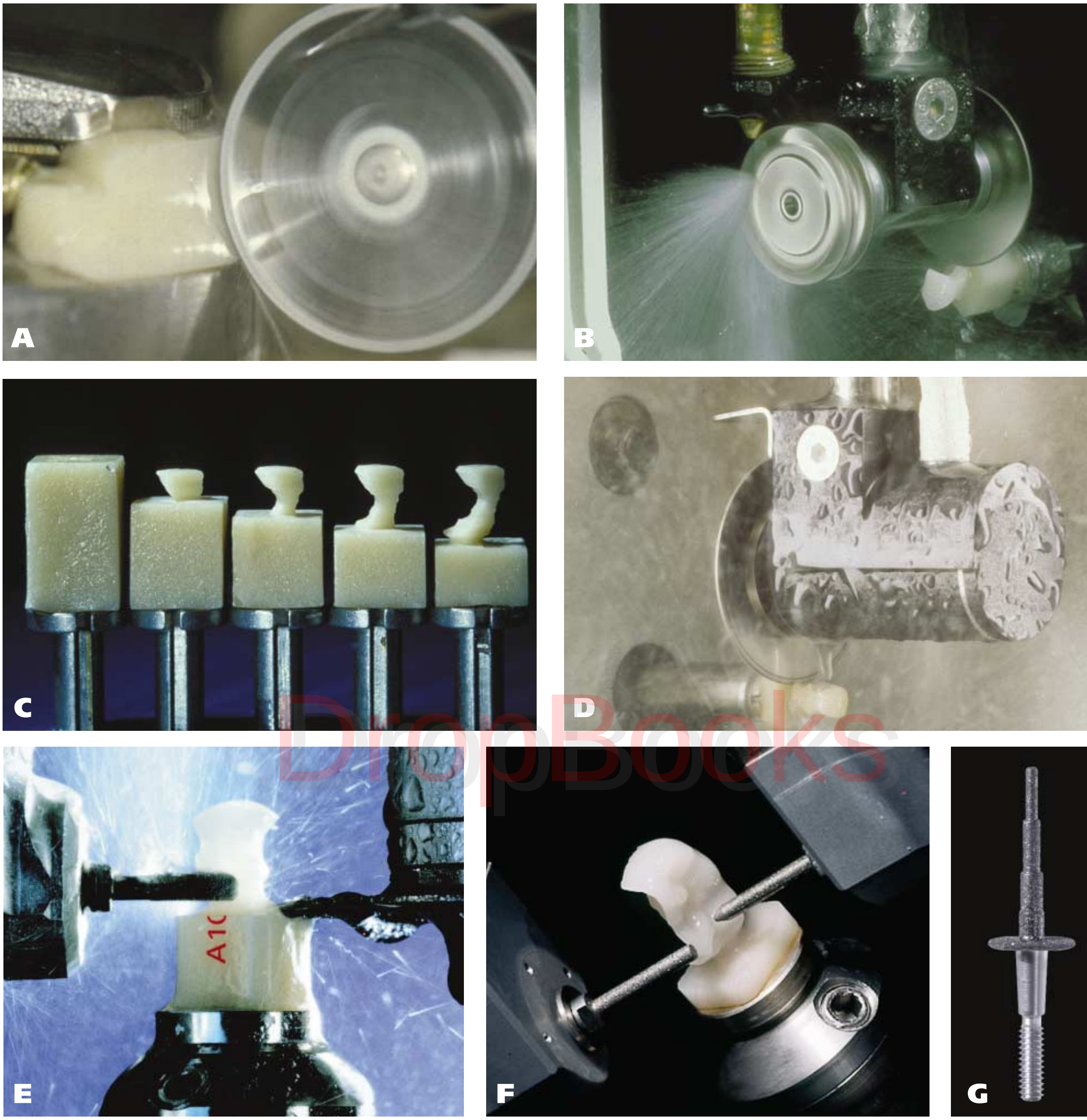


Figure 1. CEREC (Sirona Dental Systems GmbH, Bensheim, Germany) form-grinding evolution: feldspathic block ceramic. **A.** Basic grinding trial with diamond-coated wheel. **B.** CEREC 1: water turbine drive. **C.** CEREC 1: inlay emerging from a block. **D.** CEREC 1: E-drive. **E.** CEREC 2: cylindrical diamond bur and wheel. **F.** CEREC 3: cylindrical diamond and tapered burs. **G.** In 2006, a “step bur” replaced the cylinder diamond.

as these were subject to U.S. export control, because they also were used for military purposes. We therefore had to visit Fairchild’s research director in Palo Alto and convince him of the merits of our project so that we could buy a number of these CCDs and be assured of later delivery. The standard CCD—14 × 14 millimeters and 50 µm in resolution—therefore could be used.

In the spring of 1983, we employed the measuring principle, making use of a measuring grid of parallel black and bright stripes (each 250 µm wide) on the optical bank and obtained the first optical impression of a cavity. Integrating the optical and electronical system into the small dimensions of a mouth camera required a major effort, which is described elsewhere in more detail.[1,6] Our concept was that the dentist should use his or her customary work methods, that we

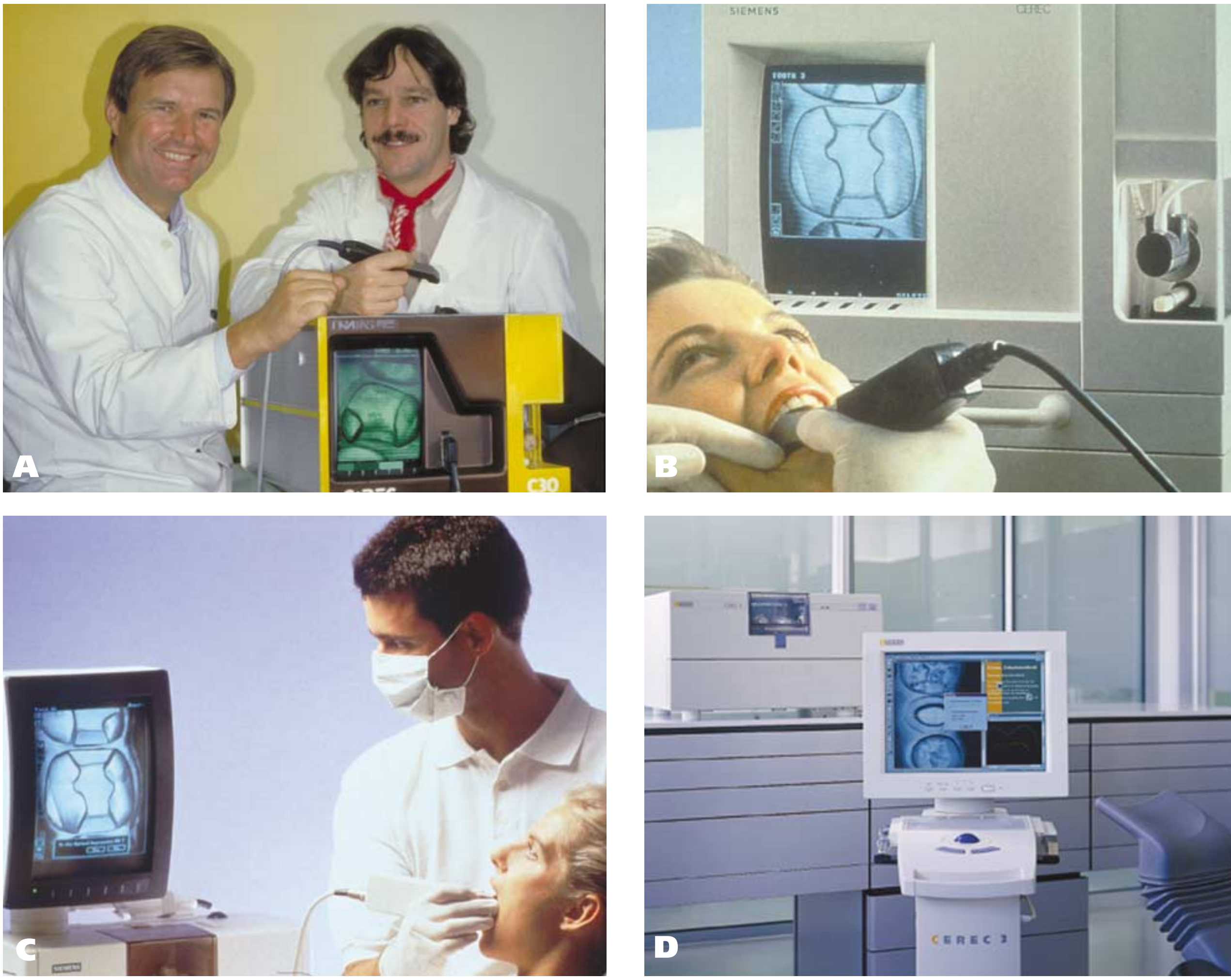


Figure 2. Evolution of CEREC hardware. **A.** 1985: the CEREC 1 prototype unit, the "lemon," with Dr. Werner Mörmann (left) and Marco Brandestini, Dr. sc. techn.ETHZ. **B.** 1991: CEREC 1, as modified by Siemens (Munich, Germany) with E-drive and CEREC Operating System 2.0. **C.** 1994: CEREC 2, with an upgraded three-dimensional camera. **D.** 2000: CEREC 3, with split acquisition/design and machining units.

must make it possible to handle the oral camera as one does the handpiece used for preparation. As we envisioned it, the dentist would align the oral camera's angle of vision for the scan according to the insertion axis of the preparation (Figures 2A, 2B and 2C), analogous to the handpiece used for the preparation, and would check this while watching the monitor image of the device. He or she would stabilize the camera by resting it on the patient's teeth. He or she would trigger the three-dimensional scanning process as soon as the direction of view agreed with the insertion axis. This is based on the knowledge that the view of the preparation in the direction of the insertion axis enables all spatial information necessary for designing inlays or crowns to be acquired with a single scan. We called this process the "optical impression." The process remains principally unchanged today (Figures 2C and 2D).

Hardware development and naming. Thus, we had the basic elements of the method in our hands. Now what had been created needed a name. We decided on the abbreviation CEREC, for "computer-assisted CERamic REConstruction." Dr. Brandestini produced the first design for the CEREC 1 unit and for the oral camera. He quickly had a clear idea about data acquisition and processing. He built the associated computer and video board, as well as the entire CEREC 1 prototype unit (Figure 2A). The CEREC 2 and 3 units, as well as the CEREC inLab and extraoral scanner (inEOS) and the associated software versions, were developed by CEREC teams at Siemens and Sirona (Bensheim, Germany). The table presents the major milestones in CEREC development.

TABLE

Major milestones in CEREC* CAD/CAM development.

YEAR	HARDWARE	SOFTWARE CAPABILITY	RESTORATION TYPE	DEVELOPER
1980	Basic concept	Two-dimensional	Inlays	Mörmann (University of Zurich) and Brandestini (Brandestini Instruments, Zurich)
1985	CEREC 1	Two-dimensional	First chairside inlay	Mörmann and Brandestini (Brains, Zurich)
1988	CEREC 1	Two-dimensional	Inlays (1), onlays (2), veneers (3)	Mörmann and Brandestini
1994	CEREC 2	Two-dimensional	1-3, partial (4) and full (5) crowns, copings (6)	Siemens (Munich, Germany)
2000	CEREC 3 & inLab	Two-dimensional	1-6 and three-unit bridge frames† (inLab‡)	Sirona (Bensheim, Germany)
2003	CEREC 3 & inLab	Three-dimensional	1-6 and three- and four-unit bridge frames† (inLab‡)	Sirona
2005	CEREC 3 & inLab	Three-dimensional	1-5 automatic virtual occlusal adjustment	Sirona

* Sirona Dental Systems GmbH, Bensheim, Germany.
† Bridge frameworks are being fabricated in Europe only, on an experimental basis.
‡ InLab only: Extended-range ceramic block spindle.

THE EVOLUTION OF THE CEREC SOFTWARE

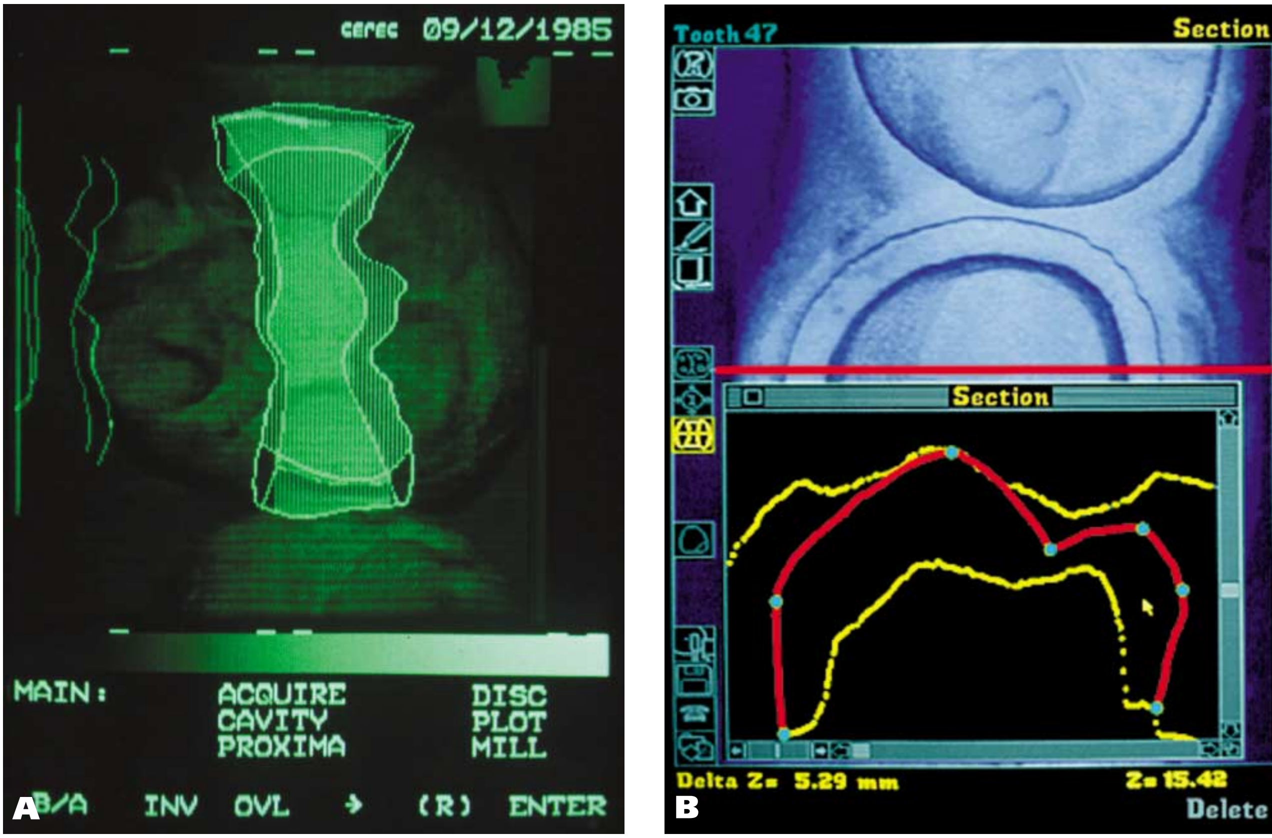
Our next question was this: how could we move from the three-dimensional data record of the cavity to the design of the inlay? To answer this, we needed a software engineer.

The world of computers and software still was in its infancy in 1983. We met Alain Ferru, Dr. sc.techn., a young French software engineer, who had studied in Zurich and was looking for a challenge. Dr. Ferru's skills suited our needs, and the project fascinated him. I explained the anatomy of teeth to him, as well as the buildup of an inlay cavity in the three basic planes: the cavity margins, the occlusion and the proximal contacts. The basic layout of the design software resulted from the requirement to mark the cavity floor, enter the proximal contact lines, find the proximal and occlusal cavity margins, adapt the floor data and build up the proximal and occlusal surfaces. Dr. Ferru programmed everything as instructed, and thus the CEREC 1 operating system was created (Figure 3A). To make the process simple and get the system running, I instructed him to program the system in such a way that it designed the occlusal surface of the ceramic inlays initially by means of the straight-line connection of opposing cavity margin points. (It was up to the dentist to develop the occlusal anatomy and occlusal contacts manually by using fine diamonds.) The Siemens CEREC team developed the CEREC 2 software, which enabled the user to create full crowns. It introduced the design of the occlusion in three modes: extrapolation, correlation and function. However, the design still was displayed two-dimensionally (Figure 3B).

The three-dimensional virtual display of the preparation, of the antagonist and of the functional registration became available with the introduction of the three-dimensional version of the software in 2003 (Figure 3C). The CEREC three-dimensional software is much more illustrative than the previous versions and makes the handling of the system intuitive and easy. The 2005 and 2006 versions include the automatic adjustment of a selected digital full-crown anatomy to the individual preparation, to the proximal contacts and to the occlusion (a feature called the "antagonist tool"). The automatic "crown settling," "cusp settling" and "virtual grinding" functions provide the dentist with a predictable method of controlling the vertical dimension of the restoration design before he or she machines the restoration.[8]

THE FIRST CHAIRSIDE CEREC INLAY

At the beginning of September 1985, all parts of CEREC 1 were functioning for the first time. Dr. Brandestini and I proudly presented ourselves



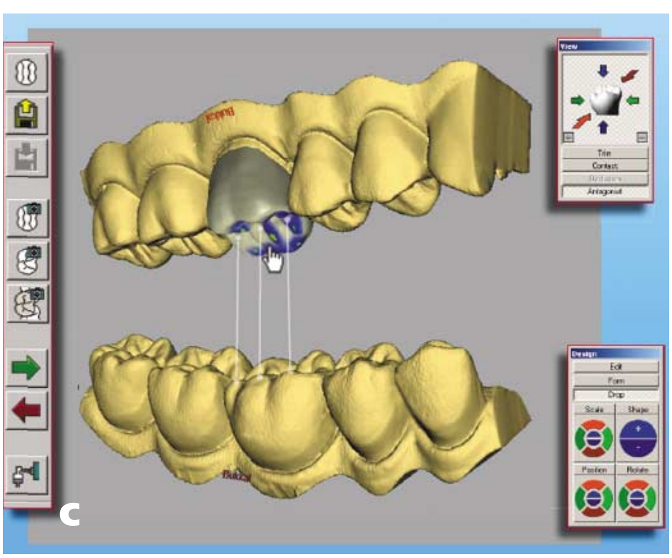


Figure 3. The evolution of CEREC software (Sirona Dental Systems GmbH, Bensheim, Germany). **A.** CEREC 1. **B.** CEREC 2. **C.** CEREC 3.

with the first functional device, which we called the "lemon" because of its yellow color (Figure 2A). The first CEREC chairside treatment took place on Sept. 19, 1985, in the University of Zurich Dental School. The material was Vita Mark I feldspathic ceramic (Vita Zahnfabrik). We had assembled a complete material set and had found a reliable material partner in Vita Zahnfabrik. We relied at that time solely on the adhesion between etched enamel and etched ceramic. This method has proven itself in private practice for 10 years.[9] We applied functional dentin adhesion routinely in the clinic from 1993 onward.[10]

Until 1985, we had knowledge only of computer-aided desing/computer-aided manufacturing (CAD/CAM) precursor studies—Altschuler[11] (1973) and Swinson[12] (1975), to name the earliest. We later became acquainted with the highly competitive work by Duret and Termoz[13] (1985) and Rekow[14] (1987), which then excited much interest in the public. We realized for the first time that there was a lot of competition in this field.

CONCLUSION

Today, the CEREC method has been proven internationally[15] and has a sibling in the dental laboratory, the CEREC inLab. However, its unique feature in dental CAD/CAM technology is that it enables the dentist to capture the tooth preparation directly in the mouth of the patient allowing the dentist to create and seat a ceramic restoration in one appointment. It appears that

the CEREC CAD/CAM concept is becoming a significant part of dentistry. ■

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